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ENVIRONMENTAL ANALYSIS OF POSSIBLE SULFUR INCREASES IN USAF JET FUELS

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This analysis addresses the question of whether environmental considerations should be the limiting constraint to possible increases in sulfur content of USAF jet fuels. Such increases are proposed in order to increase the availability of jet fuels such as JP-4. The current average sulfur content of 0.05% by weight and two hypothesized levels of 0.4 percent and 1.0 percent are analyzed in this study. Aircraft emissions and meteorological conditions around an airbase are maximized to produce predicted "worst-case" ambient air quality levels.

Analysis shows that the environmental concentrations are well within national standards under "worst-case" conditions and would not be measurable under typical conditions. Results of brief measurements by others are in agreement with this analysis. Consequently the upper limit for sulfur in jet fuels should be governed by engine durability and not by environmental considerations.

ABSTRACT

This analysis addresses the question of whether environmental considerations should be the limiting constraint to possible increase in sulfur content of USAF jet fuels. Such increases are proposed in order to increase the availability of jet fuels such as JP-4. The current average sulfur content of 0.05 percent by weight and two hypothesized levels of 0.4 percent and 1.0 percent are analyzed in this study. Aircraft emissions and meteorological conditions around an airbase are maximized to produce predicted "worst-case" ambient air quality levels. Analysis show that the environmental concentrations are well within national standards under "worst-case" conditions and would not be measurable under typical conditions. Results of brief measurements by others are in agreement with this analysis. Consequently the upper limit for sulfur in jet fuels should be governed by engine durability and not by environmental considerations.

CONTENTS

Section		Page
I	INTRODUCTION	5-6
II	AIR QUALITY SIGNIFICANCE OF SO_2	7
III	ANALYSIS TECHNIQUES	9
IV	PRESENTATION OF RESULTS	14
V	CONCLUSIONS	18
	REFERENCES	20
	DISTRIBUTION	21

ILLUSTRATIONS

Figure		Page
1	SO_2 Emissions at Selected Air Force Bases	11
2	SO_2 Concentrations versus Diurnal Time	16
3	Maximum SO_2 Concentrations versus Distance	17
4	Predicted SO_2 Concentrations Compared with Legislated Standards	19

TABLES

Table		Page
1	Williams AFB SO_2 Emissions by Operational Mode	12
2	Assumed Meteorological Conditions	13

SECTION I

INTRODUCTION

Current decreases in the availability of petroleum products are of concern to the US Air Force as a major user of jet fuels. Also, the cost to the Air Force of JP-4 jet fuel has drastically increased during the past 2 years from roughly \$0.15 per gallon to \$0.28 per gallon. Consideration is therefore being given to the feasibility of relaxing the procurement specification for the maximum allowable sulfur content in JP-4, (currently set at 0.4 percent sulfur by weight). Relaxing this specification will apparently allow for greater refining flexibility and therefore improved fuel availability and possible cost benefits.

At least two major concerns about increasing sulfur in JP-4 must be addressed. First, the durability of engine components must not be significantly degraded. Second, the environmental consequences of such an action must be considered. This report analyzes only the environmental area of concern. The request to perform this study was made by the Fuels Branch of the Air Force Aero-Propulsion Laboratory. At their suggestion, three sulfur content levels were considered. Values of 0.05 percent sulfur by weight were chosen to represent the current average level; 0.4 percent, which is the current JP-4 maximum limit specification, and 1.0 percent, to represent a hypothesized higher level for consideration. Since essentially all sulfur is oxidized to SO_2 when combusted in a turbine engine, the emission indexes are constant over all engine operating modes when normalized by fuel usage. These values were calculated to be 1.0, 8.0, and 20.0 grams SO_2 per kilogram of JP-4 fuel combusted and correspond to the 0.05, 0.4, and 1.0 percent sulfur levels, respectively.

SECTION II

AIR QUALITY SIGNIFICANCE OF SO_2

Federal emission regulations for the control of air pollution from aircraft engines do not include limits for sulfur or oxides of sulfur (ref. 1). Since individual states do not have authority to promulgate emission standards for aircraft, the only legislated limitations for sulfur are in the form of ambient air quality standards. The National Primary and Secondary Ambient Air Quality Standards are listed below (ref. 2). Primary standards are defined as levels, with an adequate margin of safety, which are set to protect general public health. Secondary standards are defined as levels below which adverse welfare effects would not normally be anticipated. These standards for sulfur dioxide are as follows:

Primary standards	- 80 micrograms per cubic meter, annual arithmetic mean
	- 365 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year
Secondary standards	- 60 micrograms per cubic meter, annual arithmetic mean
	- 260 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year
	- 1300 micrograms per cubic meter, maximum 3-hour concentration not to be exceeded more than once per year

Adverse health effects such as chronic bronchitis, acute respiratory disease, decreased lung function, cardiopulmonary symptoms, and aggravation of asthma have been positively correlated to high levels of SO_2. The presence of total suspended particulates (TSP), along with SO_2, has long been suspected to cause more severe health effects than either pollutant alone. However, increasing concentrations of SO_2 and TSP do not show a consistant correlation to aggravated health effects. Suspended sulfates show a much better correlation, but they are not routinely measured and have no established national standard. The atmospheric transformation of SO_2 to sulfates is extremely complex and will not be modeled in this analysis.

Research efforts after the establishment of national SO_2 and TSP standards have generally supported their validity (ref. 3). Pollutant threshold levels for health effects from long-term exposures are now judged to be slightly above the current standards. Thresholds may be slightly below the short-term (24-hour) standards for some effects, such as the aggravation of asthma which has been shown to occur at 180- to 250 $\mu g/m^3$ SO_2 concentrations. Any revision of current SO_2 standards or the addition of standards for sulfates will probably not occur until the biological response is further understood and better control strategies can be resolved. Consequently this analysis uses only the current SO_2 standards as a measure of environmental impact.

SECTION III

ANALYSIS TECHNIQUES

Analysis of the projected increases in sulfur was performed using the US Air Force/Argonne National Laboratory Air Quality Assessment Model (AQAM) (ref. 4). This large computerized code was developed specifically for environmental assessments such as this one. Two major programs of the AQAM were used in this analysis: the Source Inventory Program, and the Short-Term Dispersion Program. The Source Inventory Program accepts operational input information such as numbers of aircraft landings and take-offs (LTOs) per year, numbers of training "touch and go's" per year, and engine operating times in each of the LTO cycle modes. Calculations are automatically performed to produce a total pollution emission inventory in metric tons of pollutant produced per year from Air Force bases. The Short-Term Dispersion Program takes the annual emission inventory, adjusts it to the applicable monthly, weekday, and diurnal emission level, distributes these emissions over line and area geometries as they apply to specific aircraft operations, and performs physical dispersion calculations based on hourly wind direction, windspeed, atmospheric stabilities, and mixing depths.

Since the greatest increase in ambient air concentrations would occur at the locations where the emissions are greatest, emission inventories of large SAC (Wright-Patterson AFB), TAC (Nellis AFB), and ATC (Williams AFB) bases are compared. The results are presented in figure 1. Emissions of a major MAC and AFLC base were not computed but are assumed to be roughly equal or less than the SAC base (Wright-Patterson AFB) due to similarities in the number of flying operations. Table 1 provides a breakdown of SO_x emissions by aircraft operational mode at Williams AFB.

The emissions at Williams AFB are clearly higher than the other Air Force bases and are therefore used as input to the Short-Term Dispersion Program. Hypothetical meteorological conditions were chosen so that the results would be reasonably typical of "worst-case" conditions. Parameters chosen are listed in table 2. Note that the wind direction and speed are held constant at 228° and 1.0 meters per second. Since the runway is also at this angle, pollution concentrations will tend to be maximized since emissions along the entire operational line will drift toward the receptors of interest. Wind speeds could drop below

1.0 meters per second but usually only for brief periods or with other associated turbulence. Mixing depths are assumed to range from 100 meters during the night-time inversions to only 500 meters during the daytime. While any of the above parameters could be more restrictive over brief time periods, the combination of assumed values should produce results close to "worst-case" condition.

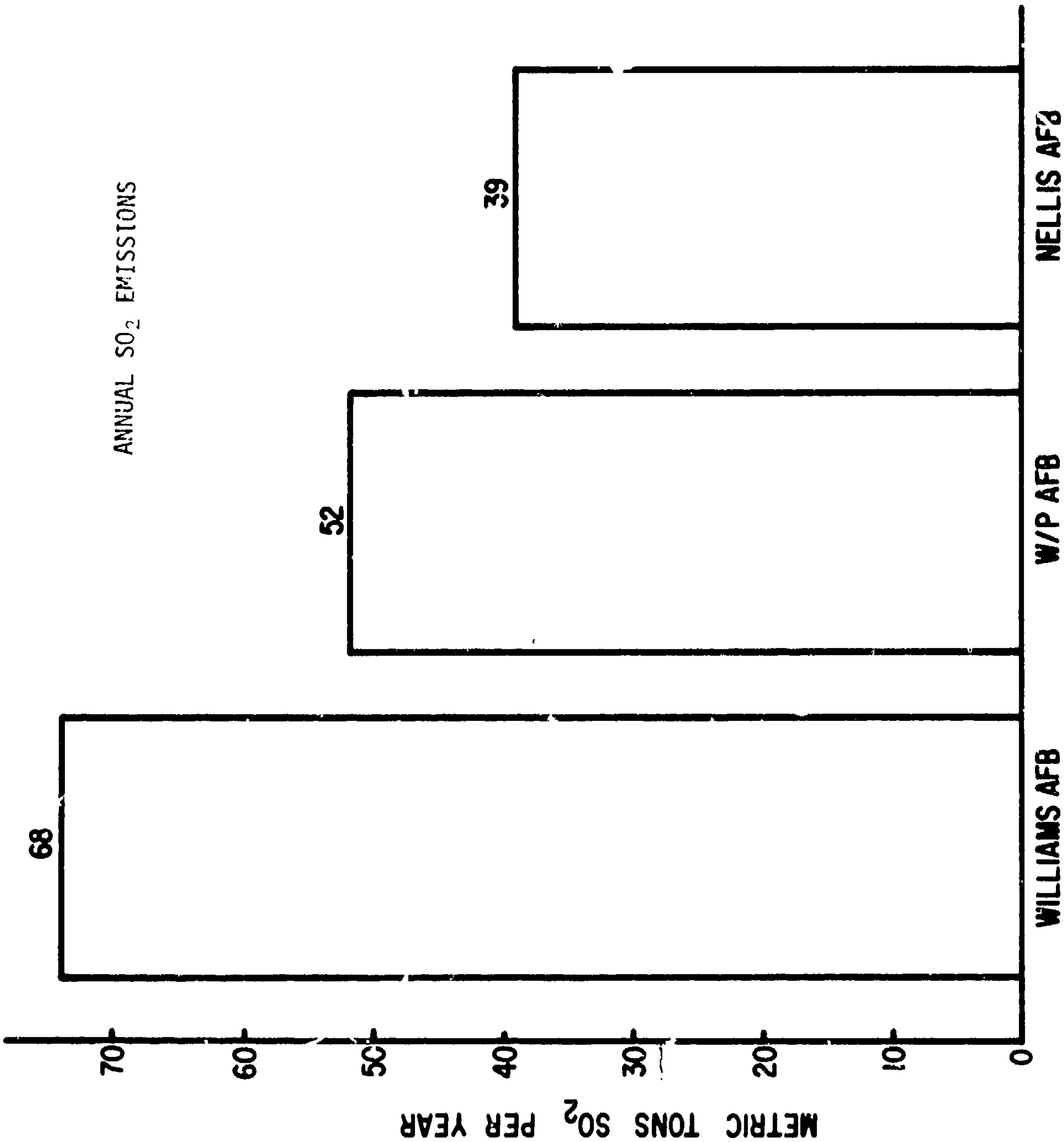

Figure 1. SO_2 Emissions at Selected Air Force Bases

Table 1

WILLIAMS AFB SO_2 EMISSIONS BY OPERATIONAL MODE

Operational mode	SO_2 emissions (metric tons/year)
1. Idle at start up	6.3
2. Taxi before take-off	11.6
3. Engine check	2.7
4. Runway roll	4.9
5a. Climbout--step 1	5.6
b. Climbout to 3000 feet	3.2
6a. Approach from 3000 feet	7.0
b. Approach--step 2	0.88
7. Landing on runway	1.7
8. Taxi after landing	9.0
9. Idle at shutdown	0.81
10. Tough-and-go operations	13.0
TOTAL, ALL AIRCRAFT	66.69

Table 2

ASSUMED METEOROLOGICAL CONDITIONS

Time	Wind direction (Parallel to runway)	Wind speed (m/sec)	Stability category	Mixing depth (meters)	Temperature (°F)
0100	227.98	1.0	6	100	66
0200	227.98	1.0	6	100	65
0300	227.98	1.0	6	100	66
0400	227.98	1.0	6	100	61
0500	227.98	1.0	6	100	59
0600	227.98	1.0	6	100	60
0700	227.98	1.0	6	100	58
0800	227.98	1.0	4	100	57
0900	227.98	1.0	4	100	64
1000	227.98	1.0	3	100	72
1100	227.98	1.0	3	250	75
1200	227.98	1.0	3	250	79
1300	227.98	1.0	3	500	81
1400	227.98	1.0	3	500	83
1500	227.98	1.0	3	500	84
1600	227.98	1.0	4	500	85
1700	227.98	1.0	4	500	83
1800	227.98	1.0	4	300	79
1900	227.98	1.0	5	100	74
2000	227.98	1.0	5	100	70
2100	227.98	1.0	6	100	65
2200	227.98	1.0	6	100	62
2300	227.98	1.0	6	100	59
2400	227.98	1.0	6	100	61

SECTION IV

PRESENTATION OF RESULTS

The tabular computer output from the Short-Term Dispersion Program indicates that maximum air quality levels of SO_2 occur approximately 2 kilometers downwind from the runway center. A receptor in this location receives pollution contributions from all ground operations, most approach operations, and some take-off operations under the assumed wind direction. Concentrations at this distance are shown in figure 2 as a function of the diurnal time. Aircraft are not normally flown between 0000 to 0600 and 1800 and 2400 and therefore produce no concentrations during those times. Maximum 3-hour average concentrations are shown to occur between 0600 and 0900 in figure 2. Causal factors include the aircraft emissions which are high during this time due to the large number of early-morning operations and little atmospheric mixing resulting from the stable night-time conditions.

Predicted average concentrations between 0600 and 0900 are presented as a function of downwind distance in figure 3. Maximum concentrations of 20.6 micrograms per cubic meter ($\mu g/m^3$) resulting from the current sulfur levels and 413 $\mu g/m^3$ resulting from the hypothetical maximum projected sulfur levels are both well below the National Ambient Air Quality Standard of 1300 $\mu g/m^3$. The very wide differences between the predicted levels and legislated levels indicate that conclusions to be drawn from this analysis would tend to be insensitive to minor errors in the assumed "worst-case" conditions or in inherent meteorological dispersion inaccuracies. Note in this figure that ambient concentrations during this peak time period are often below the sensitivity limit of instrument methods used to determine compliance with national standards.

Results of a brief measurement study by the Air Force Flight Dynamics Laboratory are in agreement with the results of this study (ref. 5). Five tests of approximately 30 minutes each were performed at a 100-feet behind KC-135 and C-135B aircraft. The West-Gaeke analysis technique with a permeation tube calibration was used. Results showed a SO_2 range from .0009 to .019 PPM over the sampling period. Since the National Ambient Air Quality Secondary standard is .02 PPM (60 micrograms per cubic meter) on an annual basis, an individual could stand 100 feet behind an aircraft continuously for an entire year and still not receive a dosage in excess of levels allowed by the standards.

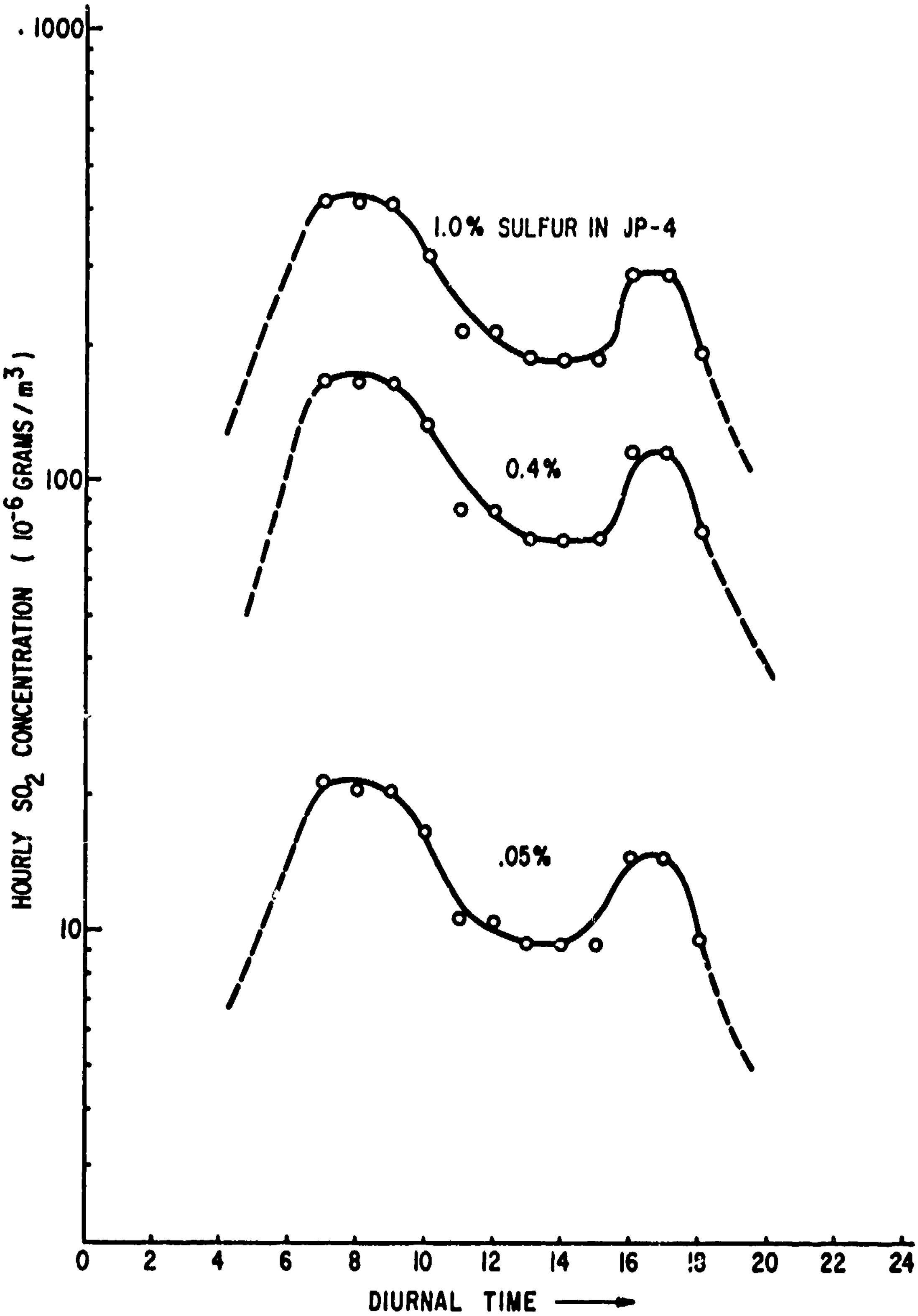

Figure 2. SO_2 Concentrations versus Diurnal Time

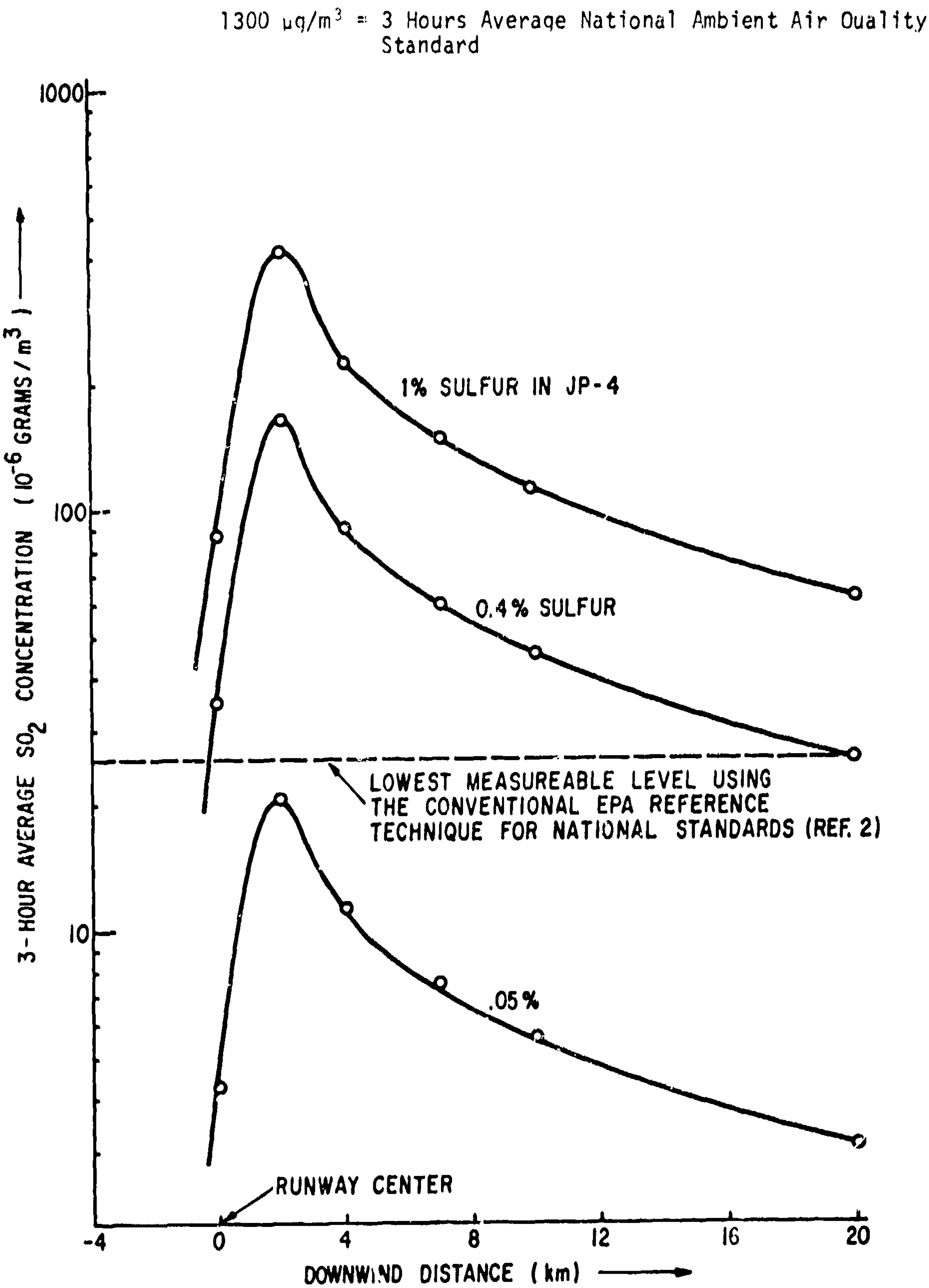

Figure 3. Maximum SO_2 Concentrations versus Distance

SECTION V

CONCLUSIONS

The predicted SO_2 ambient air quality levels are considerably below the legislated standards for projected maximum sulfur levels as well as current sulfur levels. Direct comparisons using 3-hour and 24-hour averaging times are summarized in figure 4. These projected concentrations are only for the "worst-case" situation. Typical concentrations will be even much less than these values for Air Force bases with average emission levels, wind directions other than parallel to the runway, higher wind speeds, and for receptors more distant than 2 kilometers from the runway center. Note that the difference between projected concentrations and national standards is less for the 24-hour averaging time period. This is probably due to using overly conservative "worst-case" meteorological parameters. While the assumption of a constant mean wind direction parallel to the runway may be valid for short time periods, it is unrealistic for a 24-hour averaging time. Considerable wind meander would occur during that period and would therefore tend to further reduce concentrations at any given receptor.

The conclusion is therefore made that increasing the sulfur content in JP-4 by a factor of 20, as hypothesized, would not cause serious environmental consequences. The argument could be proposed that any increase in the ambient levels of a pollutant as potentially dangerous as SO_2 is environmentally unsound. However, this analysis has indicated that under the worst conditions the SO_2 levels would reach only a fraction of the legislated environmental standards at close proximity to the airport. Under average emission and meteorological conditions, the SO_2 increase would not even be measurable. The upper limit for sulfur in jet fuels should therefore be governed primarily by engine durability factors and not by environmental considerations.

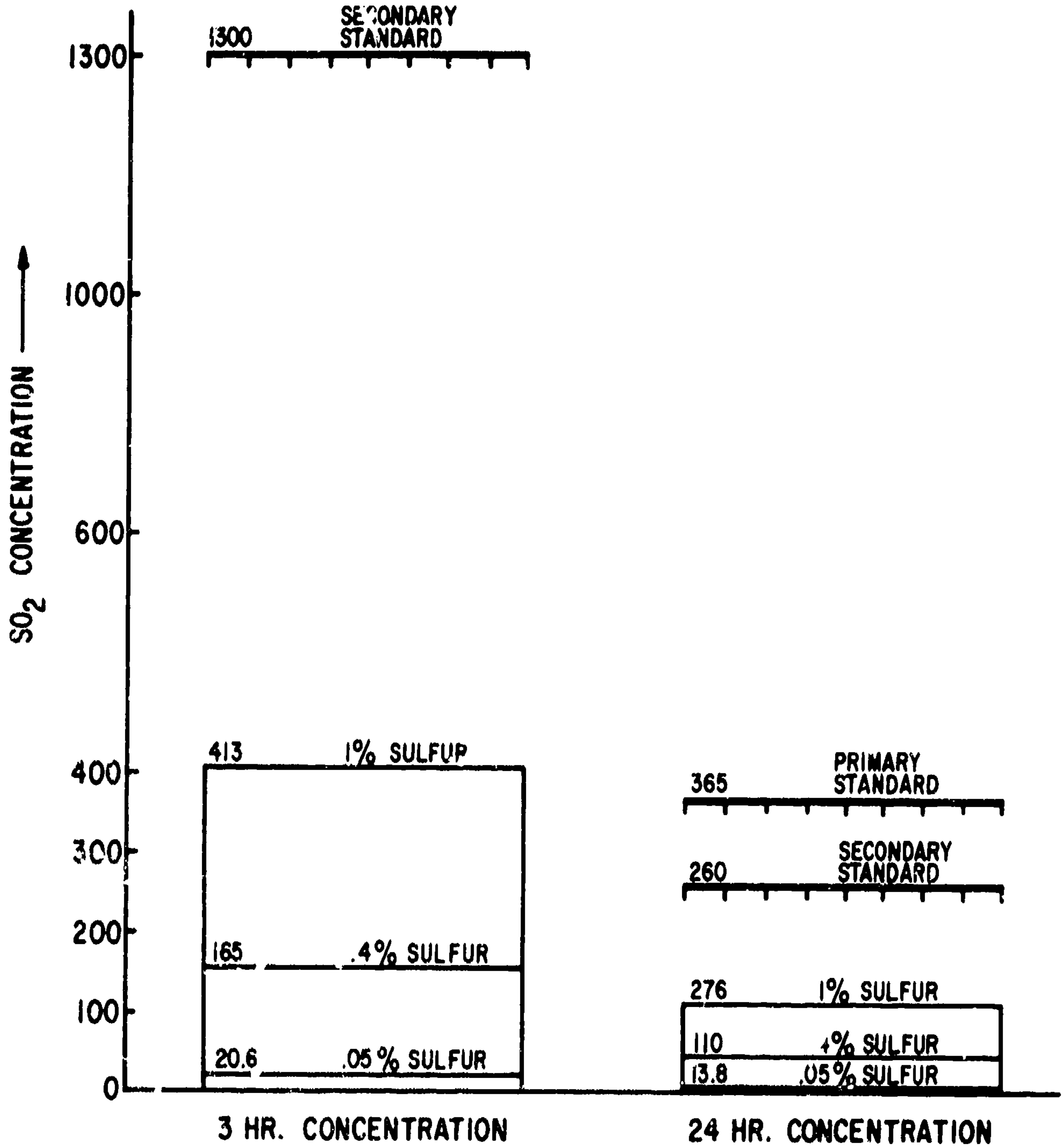

Figure 4. Predicted SO_2 Concentrations Compared with Legislated Standards

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